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Prospects of renewables penetration in the energy mix of Pakistan

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ABSTRACT

Pakistan is the sixth most populous country of the world comprising 2.56% of the total global population. However, it ranks 37th in the energy consumption, at 0.37% of the world total. The per capita energy availability is only 43 W, which is 1/7th of the world average. The greatest reason for such a huge energy deficiency is its heavy dependence on imported oil for power generation. The country is however, rich in renewable energy sources and has vast potential for their exploitation. In this article, a survey of the availability of various renewable energy sources, including hydel, solar, wind and biomass, and their current and future penetration prospects in the total energy mix have been carried out, with some recommendations. It is estimated that Pakistan has the feasible potential of 30 GW of installed power capacity from hydel and 50 GW of installed capacity from wind by 2030.

Contents

1. Introduction

One of the greatest impediments in the current economic growth of Pakistan is the huge shortfall in the demand and supply of electricity. A heavy dependence on the imported oil, which comprised 40% of all imports in 2011 with 14% trade deficit severely restricts the establishment of new industries, and smooth functioning of the already established ones [1]. The difference between the electric supply and demand has registered new heights of up to 50% in the summer of 2012, inciting large scale public outrage, nationwide demonstrations and law and order challenges for the government. Many industrialists are choosing to shift to other neighboring countries. The situation is alarming and demands immediate short term, medium term and long term measures.

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The energy demand in Pakistan is rapidly growing, registering nearly 80% growth during the last fifteen years—from 34 million tons of oil equivalent (MTOE) in 1995 to 1961 MTOE in 2010 [2,3]. Currently, it is growing at a rate of 10% per year. The current overall energy mix consists of 46% indigenous natural gas, 35% imported oil, 12% hydel, 6% coal and 2% nuclear. The currently installed electric power generation capacity is 21 GW, but the actual generation remains limited between 9 GW to 13 GW, while the actual demand fluctuates between 16 GW to 19 GW. The current electric power generation comprises of 27% indigenous natural gas, 36% imported oil, 32% hydel and 5% others including coal and nuclear. This mix, though already a huge burden on national economy due to oil imports, is under severe threats due to rapidly diminishing domestic gas reserves, which are the second major contributors to electric power generation. The electric power demand in the country is growing at a rate of nearly 8% per year, as shown in Fig. 1.

While the prospects for the discovery of new local oil and gas reserves are not very encouraging, a huge untapped renewable energy resource exists in the country.

2. Renewable energy potential in Pakistan

Pakistan occupies a land area of 803,950 km^2, and a coast line of 1146 km. There are four main sources of renewable energy, namely hydel, solar, wind and biomass, which have substantial potential to overcome the energy shortage problem in the country. A steady growth in their effective penetration in the energy mix of the country is crucial to address the existing energy challenges. So far Pakistan has set a target to add 10,000 MW to its energy mix through renewables by 2030 [4], though the actual growth potential seems to be much higher. Potential of each form of renewable energy source has been examined in the following sections.

2.1. Hydel power

The hydel and thermal power plants account for 95% of the total electricity generation in Pakistan, with respective shares of 35% and 65%. The thermal power share comes from three sources—Government owned Power Generation Companies (GENCOs), Independent Private Power Producers (IPPs) and Rental Power Plants (RPPs), with respective shares of 23%, 43% and 3%. The electricity produced by the hydel sources costs 1.25 ¢/kW h, while the one supplied by IPPs and RPPs costs 11.8 ¢/kW h and 17.3 ¢/kW h, respectively [5,6]. Thus, the per unit electricity supplied by the thermal sources costs up to 14 times as much as that of the hydel sources. This places a huge burden on the national economy due to the substantially dominant role of the thermal sources.

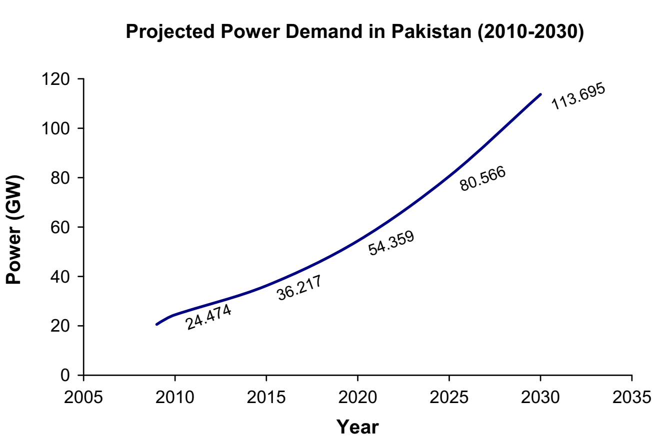

Fig. 1. Current and projected power demand in Pakistan—2010 to 2030 [5].

Pakistan is situated between the Arabian sea and the three great mountain ranges namely Himalayas, Hindukush and Karakoram. The area has great economic, political and strategic importance. It has five major rivers namely Ravi, Sutlej, Beas, Chenab and Jhelum, which ultimately fall into the grand Indus River. With current water storage capacity of 15 million acre feet (MAF), Pakistan can store only 13% of its annual rivers flow of 136 MAF. An average of 35.2 MAF flows down to the Arabian sea every year [5]. To save and utilize the available water, construction of additional storage facilities is essential for sustainable irrigation and power production. The per capita annual water availability in Pakistan was 5260 m^3 in 1951 when its population was 34 million, but now with a population of 186 million, it has reduced down to 962 m^3. Pakistan has reached the stage of "acute water shortage".

The above mentioned rivers in the Pakistan′s mountainous terrain have an estimated combined electricity generation potential of over 100 GW with 48 identified sites of 59 GW [5]. The major share of the identified sites (74.9%) is with the Indus river basin (13 sites), while Jhelum river basin (10 sites) has 13.6% share. The remaining 11.5% share is with smaller Swat river (3.9% with 5 sites), Chitral river (3.8% with 4 sites) and small (below 50 MW) hydropower projects (3.8% with 16 sites). Pakistan Water and Power Development Authority (WAPDA) has carried out feasibility studies and engineering designs for several hydropower projects with combined capacity of over 21 GW. Table 1 shows the currently installed hydel power generation capacity in Pakistan, while Table 2 shows the capacity to be added until 2015, bringing the total hydel power capacity to over 8 GW.

Table 3. shows the identified sites for hydel power projects in Pakistan whose feasibility study is complete. In most cases the detailed engineering designs are also complete, while construction work on the first two projects has already commenced. For the last three projects, which are under the public–private partnership scheme, EOIs have already been invited. If all these projects – which are technically ready for launching – get materialized during the next seven to fourteen years, will bring the total installed hydel power capacity in Pakistan to over 29 GW. They will also nearly double the current water storage capacity. Increasing the water

Table 1
The currently installed hydel power generation capacity in Pakistan. Based on data from [5].

S. No	Power station	Installed capacity (MW)
1.	Tarbela	3578
2.	Ghazi Barotha	1450
3.	Mangla	1000
4.	Warsak	243
5.	Chashma	184
6.	Khan Khwar	72
7.	Duber Khwar	130
8.	Allai Khwar	121
9.	Others	178
	Total Capacity	6956

Table 2
Near completion hydel power projects in Pakistan. Based on data from [5].

S. No.	Power station	Capacity (MW)	Expected completion
1.	Jinnah Hydropower	96	Dec. 2012
2.	Gomal Zam Dam	17.4	Feb. 2013
3.	Golen-Gol	106	Feb. 2015
4.	Neelum Jhelum	969	Oct. 2015
	Total	1188.4	

Table 3
Identified sites for hydel power projects in Pakistan whose feasibility study is complete. Based on data from [5].

S. No.	Project	River	Water storage (MAF)	Power capacity (MW)
1.	Diamer Basha	Indus	8.1	4,500
2.	Kurram-Tangi	Kurram	1.2	84
3.	Tarbela-4th Extetnsion	Indus		1,410
4.	Munda	Swat	1.3	740
5.	Kohala	Jhelum	RoR[a]	1,100
6.	Bunji	Indus	RoR[a]	7,100
7.	Dasu	Indus	1.15	4,320
8.	Lower Spat Gah	Indus	RoR[a]	496
9.	Lower Palas Valley	Indus	RoR[a]	665
10.	Mahl	Jhelum	RoR[a]	600
	Total Capacity		11.75	21,015

[a] RoR is "Run of River".

storage capacity is critical to irrigate an additional 20 million acres of land (from the current 52 million acres) in order to feed the rapidly increasing population of the country. This will bring the maximum cultivatable land to its limit of 72 million acres [5]. Even the sustainability of the current irrigation capacity is in serious jeopardy due to the sedimentation of the existing water reservoirs, which has reduced the capacity by over 5.5 million acre feet over the years. Even after the completion of the above projects, Pakistan will need to build several times more water storage capacity to withstand the climatic challenges like droughts and floods.

In addition to the above identified sites, there are indicated sites of over 30,000 MW combined capacity whose feasibility study or detailed engineering design is underway.

2.2. Solar power

Pakistan consists of four major provinces namely, Punjab, Sindh, Khyber-Pakhtunkhwa and Baluchistan, in addition to Federally Administered Tribal Areas (FATA), Gilgit-Baltistan and Azad Kashmir. These units respectively comprise 25.8%, 17.7%, 9.4%, 43.6%, 3.4%, 9.1% and 1.5% of the total area of the country. A recent study [7], based upon thirty year's data (1971–2000), obtained from 58 meteorological stations, spread all over the country, has been carried out to estimate the global solar radiation. The study indicates that more than 70% of the 0.8 million km^2 area of the country receives an annual average solar radiation energy of 5.0–5.5 kW h/m^2/day. There are sizeable pockets near Quetta, Qalat, Khuzdar and Zhob in the province of Baluchistan and Larkana in the province of Sindh, which receive 5.5–6.0 kW h/m^2/day, as shown in Fig. 2. The study has utilized the sunshine duration, mean maximum and mean minimum temperatures and extra-terrestrial radiation data to infer the results. The estimates made in this study are on the average more conservative by about 0.5 kW h/m^2/day, compared to the estimates made by the National Renewable Energy Laboratory (NREL) of USA [8].

The actually measured long duration (27 years) solar radiation data collected by the Pakistan Meteorological Department is available for five major cities of Pakistan as shown in Fig. 3. This indicates that Quetta receives a yearly average of 21.65 MJ/m^2 of solar radiation energy per day, with a maximum of 29.68 MJ/m^2/day in the month of June. This corresponds to an annual average of 6 kW h/m^2/day and a maximum of 8.25 kW h/m^2/day solar resource. The annual averages for Karachi, Multan, Peshawar and Lahore are 19.25 MJ/m^2/day, 18.7 MJ/m^2/day, 18.36 MJ/m^2/day and 17.0 MJ/m^2/day, respectively. For the mono-Si-HiP-190BE2, mono crystalline silicon PV modules with 16.1% conversion efficiency,

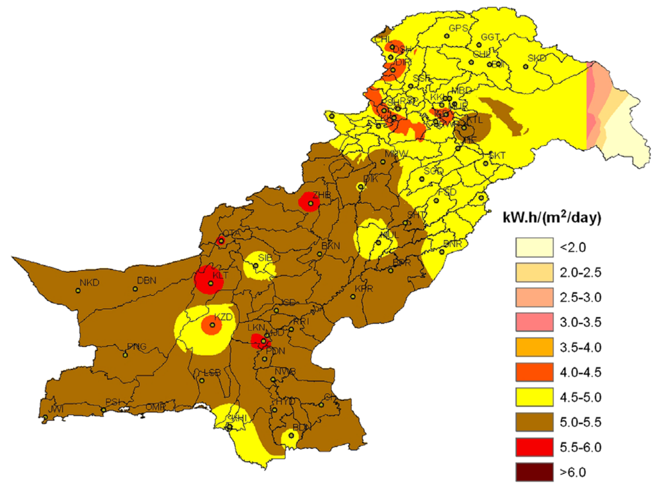

Fig. 2. The yearly average solar radiation energy on a horizontal surface at different locations in Pakistan, calculated using Angstrom equation and Hargreaves formula with 30 year's meteorological data of sunshine, mean maximum and mean minimum temperatures, and extraterrestrial radiation. Reproduced with permission from [7].

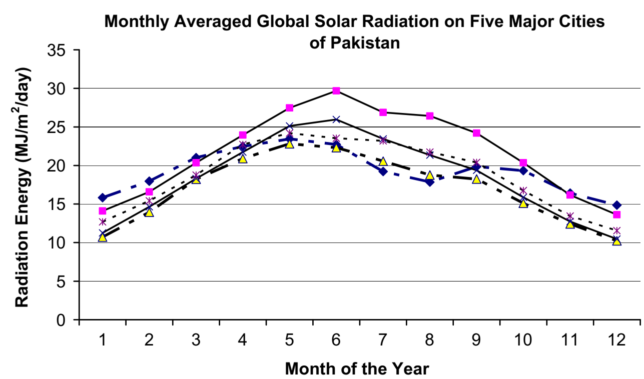

Fig. 3. Monthly average global solar radiation on Quetta (top curve ■——■——■), Peshawar (second curve from the top ●—●—●), Multan (*——*——*), Karachi (◆▬ - ▬◆▬ - ▬◆) and Lahore (bottom curve ▲—▲—▲), based upon 27 years (1957–1983) measured data from [9].

it is estimated that a 10 MW power plant will require 62,112 m^2 of collector area with one axis tracking in Quetta [10].

Other studies [11,12] have calculated the distribution of global and diffuse solar radiation in several cities, using various techniques. All results whether direct or inferred, indicate that Pakistan located between 24 degrees and 37 degrees North latitude and 62–75 degrees East longitude [13], has amongst the best solar radiation resource in the world. There is therefore a very high potential for harnessing the solar energy in different ways. It may be interesting to note that four of the five areas with highest solar insole, as seen in Fig. 2, are located in the province of Baluchistan, which though contributes 43.6% to the total area of the country, houses only 5% of the total population. This means that large scale solar power plants established in Baluchistan will require the establishment of a large transmission network to the more populated areas of the country. This situation is similar to the hydel power projects (current and future), which are mostly located in the northern parts of Pakistan with relatively little population. The Alternate Energy Development Board (AEDB) of Pakistan estimates that altogether 2900 GW of solar resource exists in the country [14,15]. Each square kilometer area as shown in brown color in Fig. 2 can generate about 60 MW of peak and 15 MW of average power, through solar thermal power plants [16].

In almost all of Africa, Pakistan, Hawaii, Italy and large portions of Japan, the price of electricity is already in excess of what the cost of electricity would be from solar [17]. There is therefore a ready market in these areas for harnessing the solar power.

2.2.1. Solar PV

So far, no work has been done in the country to harness the solar power using CSP. However, the use of solar PV is on the rise with high annual growth. More than 830 companies in Pakistan are involved in businesses related to solar PV, water pumping, street lighting, air-conditioning and small domestic appliances.

The world wide PV installed capacity was 62 GW by the end of 2011, with nearly 70% annual growth during the last five years. The Chinese solar PV inverter market grew by over 400% in 2011 to over 2.5 GW in shipments [18]. In general the PV prices fell down to 70–80 ¢/W in 2011, and are expected to touch 45 ¢/W by 2015 [19,20].

Pakistan′s first 356 kW solar power grid station has been installed in Islamabad in May 2012, through a grant assistance from JICA [21]. A one MW solar PV power plant with 18% capacity factor is being planned by Wah Industries in its own premises, in a village called Sanjwal, some 100 km west of Islamabad [22]. Islamia University Bahalpure is also planning to install a three MW PV plant in the near future. It is anticipated that large scale solar PV plants will pick up after 2020, inspired by falling prices and progress in neighboring India. Pakistan Council of Renewable Energy Technologies (PCRET) has installed 300 Solar PV systems with total capacity of 100 kW, electrifying 500 houses, mosques, and schools and 265-street and garden lights in different cities [18]. The Alternate Energy Development Board (AEDB) electrified approximately 3000 households with total PV power generation of 200 kW, while providing 80 W panels with lighting systems to each household [23]. A number of NGOs including Agha Khan Foundation have installed PV modules in various parts of the country. Installation of solar street and garden lights is particularly gaining rapid popularity. A massive plan to install solar tube wells with a cost of USD 16 million is underway with the Punjab government [24]. Pakistan has set a target to electrify 7000 villages through solar PV until 2015 [25], while ultimately a total of 40,000 villages may be electrified this way [23].

2.2.2. Solar water heating

Solar water heating systems have become increasing popular in Pakistan during recent years with average 250% annual growth during the last four years [26]. There are currently more than 50 suppliers of imported solar geysers and 20 domestic manufacturers in Pakistan [27]. The main reason for their increasing dissemination is their affordability, robustness and technological maturity, in addition to the increasing shortage of natural gas. Their pay back periods in Pakistan are 18–24 months, when compared with the fuel costs of the natural gas. It is anticipated that some 10,000 units will be operational in Pakistan by 2015, and 25,000 units by 2020, even in the absence of any government subsidies [4]. Currently, there are absolutely no barriers in their large scale adaptation.

2.2.3. Solar cooking

More than one third of the total primary energy consumption is accounted for cooking in the South Asian countries [28]. Large scale dissemination and adaptation of solar cookers can therefore have a very positive impact on the overall energy demand of these countries. Solar cookers can, not only provide energy security to a large segment of the population, but may also help in reducing the current high rates of deforestation. Currently, more than 5000 solar cookers are in use in Pakistan, but this number is far less than that being used in China (60,000) and India (about 640,000) [31,32]. There is therefore a huge market potential in the country in this sector. The only need is to develop more mature and user friendly versions of solar cookers for their wide acceptability. The barriers in the adaptability of the currently available solar cookers are slow cooking processes, frequent requirement of solar tracking, low cooking temperatures and non-availability of sun during more than 60% of the day. While a number of authors/inventors have proposed a number of innovative designs to overcome most of the above barriers, focus is now being laid on developing solar energy storage capsules using phase change materials for use during non-sun periods [28–30]. Such a technology will take some time to mature.

PCRET has developed several box type and parabolic type solar cookers and distributed hundreds of them in the local villages. It has a target of disseminating some 100,000 of them by 2015 [4]. In addition, PCRET has developed and distributed hundreds of solar water desalinaters of up to 250 gallons/day capacity, and over a hundred solar dryers of 500 kg capacity each, in the rural areas of the country [23,31]. The solar driers are being effectively used for drying of dates, apricots, grapes and other fruits and vegetables during high season, while solar desalinaters/stills are very effective in providing clean drinking water to rural and dispersed population patches, as well as urban communities where quality of water supplied through pipelines is not fit for drinking.

2.3. Wind power

Pakistan Meteorological Department (PMD) carried out a wind power potential survey of the coastal areas of Sindh and Baluchistan during 2002 to 2004. Round the clock wind speed and wind direction data was collected at 44 locations at 10 m and 30 m heights. The three year′s data was used to extrapolate the wind power potential at 50 m heights [33]. The best wind power resource was identified at the so called ‘Gharo-Corridor’ (Fig. 4) with 44,000 MW of gross resource and 11,000 MW of exploitable potential with 25% average capacity factor. The total area of Sindh identified for wind farming is nearly 10,000 km^2 [34]. The average annual wind speed at 50 m height is 7 m/s, and a Bonus 600/44 MK IV wind turbine is estimated to have a capacity factor of 28%. The levelised cost of electricity generation through 15 MW/km^2 wind farms consisting of 25 Nordex N43/600 wind turbines has been estimated to be between 4 ¢/kW h and 5 ¢/kW h in the coastal areas of the province of Sindh [34,35]. It is therefore quite economical to exploit the identified potential of 11,000 MW in this wind corridor. Further wind speed measurements were carried out at 50 m height at Gharo in 2006. The collected data were extrapolated to 80 m height using the WAsP version 8.03 (Wind Atlas Analysis and Application Program) software, and benchmark wind speeds were determined to provide guaranties of wind flow on behalf of the government of Pakistan to the investors [36]. According to this study, the average power potential at 80 m height is 13.5% higher in Gharo and 35% higher in the Jhimpir site, as compared to the one at 50 m height.

In the second phase PMD has collected wind data of another 42 sites in the Northern Areas of Pakistan. Seven sites (Sheedgali, Fatehpur, Dargai, Shahida Sir, Besham Qila, Moorti Pahari and Tarbella) out of the 42 sites have shown a capacity factor between 10% and 18% for the Bonus 600/44 MK IV wind turbine at 50 m height [37]. Though the complete analysis of the potential of these sites is still underway, it is apparent that these areas have relatively limited capability to contribute to the national grid, but they may be good for harnessing small scale wind power. The wind map developed by the NREL, USA in collaboration with USAID, has indicated a gross wind resource of 346 GW in Pakistan, of which 120 GW is technically extractable for centralized grid connectivity [38,39]. A study has analyzed the Indian wind energy growth as a comparative model for Pakistan [38]. While drawing

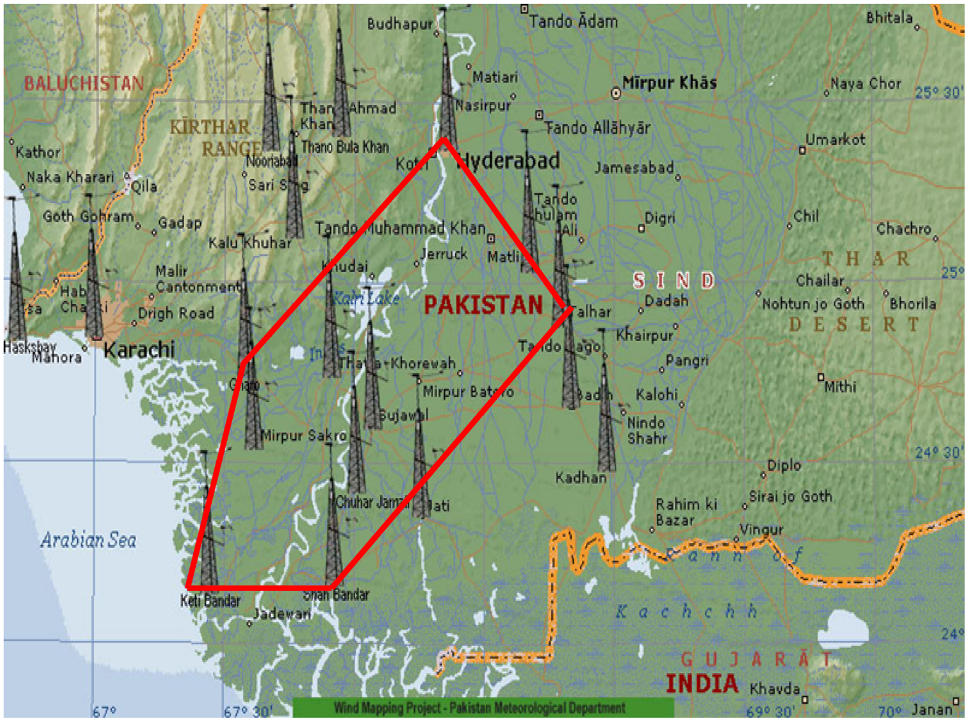

Fig. 4. Gharo-Corridor in Sindh, around the Indus river, with exploitable wind power potential of 11,000 MW at 50 m height. Source PMD. Wind was mapped at 11 locations in the corridor area.

parallels between the two countries, the study predicts in the logistic growth model, that in a standard scenario Pakistan will have an installed capacity of more than 40% (50 GW) of its maximum wind power potential, by the year 2030 and over 80% (100 GW) by 2036. With 25% capacity factor, this corresponds to 12.5 GW of added average capacity by 2030 GW and 25 GW by 2036.

Currently, 500-megawatt wind power projects are likely to be completed by six companies before the end of 2013 [15]. The Alternative Energy Development Board (AEDB) has received offers from 17 more companies for the installation of 3000 MW wind projects in the country [40]. At present, 6 MW First Phase of Zorlu wind power project is operational and construction for complete 56.4 MW is underway. The first 50 MW project of FFC Energy has just completed and grid connected. The National Electric Power Regulatory Authority (NEPRA) has determined tariff for five projects, while eight more IPPs have filed tariff petitions and generation license applications after signing EPC contracts. Further, 18 bankable feasibility studies have been completed by the IPPs which are at different stages of approval and 35 IPPs holding LOIs from AEDB are pursuing development of wind power projects. Land has been allocated to 18 IPPs for 50 MW wind power projects each, and electricity tariffs have been approved for 14 [40]. Projects with a cumulative capacity of 900 MW are at various stages of development on these lands. On the other hand, Descon is now locally producing wind turbine towers while Heavy Industries Taxila is negotiating turbine assembly with the leading wind manufacturers. The government incentives for faster wind power growth include state guarantees towards risks related to variable wind speeds, guaranteed electricity purchase, protection against political risks, attractive tariffs, Rupee/Euro/Dollar parity, carbon credits, exemption on import duty on equipment, income tax/sales tax and withholding tax and permission to issue corporate registered bonds.

On micro wind side PCRET has installed 155 small wind turbines (0.5 KW to 10 KW) with total capacity of 161 KW in Sindh and Balochistan, electrifying 1560 houses and 9-coast guard check-posts [4]. Currently, more than 1000 small wind turbines (300 W to 1000 W capacity) provided by the various NGOs including Agha Khan Foundation are operational in the remote areas of Sindh. There are more than 30 companies in the country which are associated with small scale wind energy business [41]. More recently, PCRET has electrified three villages of Balochistan using wind/PV/diesel hybrid systems.

2.4. Biomass

There are over 57 million animals (Buffaloes, cows) in Pakistan, which can generate more than 21 million m^3 biogas and 36 million tones of bio-fertilizer per day. More than 4000 biogas plants have been installed by PCRET throughout Pakistan for meeting domestic fuel needs of house holds, besides producing bio-fertilizers. These plants have been installed on cost sharing basis, where 50% cost is borne by the beneficiary [4]. The annual biogas generation capacity of these plants is more than 2.5 million m^3 along with production of 4 million kg/year of fertilizer. Biogas plants are currently one of the fastest growing renewable energy technologies in Pakistan. PCRET has a target of installing 50,000 biogas plants by 2015, which will produce 110 million m^3 biogas per year [4,42,43]. Alternative Energy Development Board (AEDB) with the help of NREL from USA, GIT from Germany and Risoe from Denmark, has identified the Bagasse Cogeneration potential of 1800 MW and Waste to Power potential of 500 MW [44,45].

Recently, AEDB has issued Letters of Intent (LoI) to set up a 11-MW biomass to energy power plant at Jhang (Punjab) and a 12-MW and a 9-MW biomass to energy power plant in Sindh, based exclusively on agricultural waste (cotton stalk, rice husk, sugarcane trash, bagasse, wheat chaff and other crops as multi-fuel sources).

3. Penetrability of the various RE sources in the total energy mix

It may have become apparent through the preceding discussion that the current energy shortage in Pakistan can be addressed by

suitably integrating the four main renewable energy sources into the total energy mix. The hydel resource is at the most advanced stage of technical maturity in terms of being most cost effective and completed feasibility studies. The only barriers in the rapid integration of this resource are the capital costs and the political will. Every effort should be made to bring the installed hydel power capacity to 30 GW by 2030, which has much higher capacity factor than wind or solar.

Wind power has taken a slow start with current 100 MW installed last year, but is now gaining momentum and is expected to grow more rapidly. It is anticipated that by 2030 up to 50 GW can be installed at nearly 25% capacity factor. The contracts of projects underway have been signed at 11–16 ¢/kW h, which are higher than the current grid electricity price, but lower than that of the rental power plants [46].

On the average, Pakistan receives 7.6 h of sunshine per day with average solar radiation of 5–7 kW h/m^2/day over more than 95% of its area with persistence factor of over 85% [23]. The total solar resource is nearly 25 times as much as that of the wind or hydel alone. Solar PV has high potential to fulfill the distributed energy demand of more than 30% population living in villages, where grid connectivity is extremely difficult. It has been estimated that solar PV will achieve grid parity in Pakistan if a 10 MW power plant at 26% capacity factor has a capital cost of $ 35 million [10]. This target is in sight within the near future. Large grid connected solar thermal power plants may also pick up after 2020. Therefore, though not exactly quantifiable as yet, solar power is expected to start making meaningful contributions by the end of the current decade.

Total biomass potential in Pakistan is estimated at about 5.7 GW at 100% capacity factor (50,000 GW h/year). It can be utilized very effectively for addressing energy demand in the rural areas, as well as supplement the urban power houses. It is currently the fastest growing RE technology in Pakistan, where more than 4000 biogas plants are in operation and 57 MW combined capacity power plants are either already operational or are in the pipeline. The major sources of biomass energy are crop residues, animal manure and municipal solid wastes, with relative shares of 25%, 50% and 25%, respectively [47,48].

The governmental policy on the penetration of renewable energy in the total energy mix was charted out in 2006 with four strategic objectives, namely energy security, economic benefits, social equity and environmental protection. The short term (up to 2008), medium term (up to 2012) and long term (beyond 2012) goals were chalked out. The focus during the short term goals was on RE options amenable to immediate commercial development. This included focus on the commercially-proven technologies and resources which are readily available, such as small hydro, wind, solar, and biomass-based power generation. The most prominent features of this phase were the liberal risk cover and attractive power purchase tariffs so as to enable a reasonable generation capacity to be installed as 'first-of-kind' RE projects in the private sector that could serve as successful business and technology-assimilation demonstrators. Work was also carried out on developing an appropriate regulatory framework, market and resource assessment, rural energy program designs, pilot testing of dispersed generation systems, capacity building, and development of RE financing and market facilitation measures. The medium term plans incorporated a more comprehensive policy framework for the systematic implementation of RE technologies and scaling up of capacity deployment. This framework laid greater emphasis on competition within an RET application category as well as the programmatic development of dispersed RE power generation market, with reduced subsidy and risk cover. The long term policy targeted the development of fully mainstreamed and integrated RE technology within the nation′s energy planning process. It has the aim to bring the widespread RE use at the rural and urban household level, supported by an established local manufacturing and service base [49].

4. Barriers and recommendations

A number of barriers have prevented the rapid integration of renewables in the energy mix of Pakistan during the last two decades. These barriers include policy and regulatory barriers, institutional barriers, fiscal and financial barriers, market-related barriers, technological barriers and information and social barriers [44,50]. Some of the barriers like policy and regulatory barriers have been addressed by the AEDB during the last few years. As a result visible changes are in sight in as far as wind, solar PV and biomass forms of renewable energy are concerned. Wind farms with combined generation capacity of 900 MW are currently in the pipeline.

However, the remaining barriers are yet to be addressed. The current "circular debt" is also a major issue for the energy sector and has become a significant barrier for energy development in Pakistan. Urgent reforms in the power sector are also required to grow power generation capacity, enhance transformation efficiency and improve the distribution network. The following recommendations are made to enhance the renewables penetration in the Pakistan′s energy mix:

- Priority should be assigned to more rapid and targeted development of hydro-power plants for which there exists a substantially large potential and for whom feasibility studies have already been completed.
- Grid flow of wind power has already started last year. However, in the absence of basic infrastructure, like availability of large cranes, insufficient road network and insufficient grid integration capability, the pace of development is relatively slow. This may be boosted up by prioritizing the provision of these facilities.
- Development of cheap and user friendly solar cookers should be made a priority, as rapid integration of these cookers can have profound impact on the overall energy demand in Pakistan.
- Effective and frequent public demonstrations be carried out to increase the acceptability and penetration of solar cookers, solar water heaters, solar water purifiers and solar dryers.
- Official campaigns be initiated to educate the general public regarding the environmental and commercial benefits of green energy.
- Site specific feasibility studies be carried out for the installation of large scale grid connected solar PV and solar thermal power plants.
- Net metering system be introduced to purchase power from the small scale wind, solar and biomass power producers.
- More and more students be sent abroad for acquiring training in the emerging renewable energy technologies.
- Courses on renewable energy be introduced from the primary to the university levels in the educational system of the country to develop public consensus in favor of adopting renewables as energy sources and locally train the required man power to address the emerging renewable energy market demands.
- Policies should be framed for the wide dissipation of easily payable loans for buying and installing small scale renewable energy systems by the end users.
- Policies should be framed for facilitating the development of indigenous capabilities as well as the effective transfer of newer technologies from abroad, in the energy sector.
- Law and order situation be improved to encourage and attract the local and foreign investors to invest in green energy.

- A vast amount of experience in the renewable energy sector may be drawn from the neighboring China and India, with whom lots of cultural practices and social setups are in common.

5. Conclusions

Pakistan is currently a water and power deficit country. There is 25% to 50% shortfall in its current peak power demand of around 18.5 GW, while the power demand is increasing at 8–10% per year. The known oil and gas reserves of Pakistan are near exhaustion, and import of oil is now accounting for 40% of its total imports [51]. The country is under a severe energy crisis. But there is a huge potential in the country for the penetration of renewables. The total hydel power potential exceeds 100 GW, Solar power 2900 GW, wind power 120 GW and biomass 5.7 GW. The identified resources whose feasibility reports are complete, are 21 GW hydel, 3.5 GW wind and 0.15 GW biomass. No feasibility surveys have yet been carried out for harnessing the abundant solar power. The hydel power is the cheapest resource with dual benefit, as it can also address the water scarcity problem with added storage capacity. The above renewable energy sources are fairly distributed amongst the different provinces. Province of Khyber-Pakhtunkhwa in the North-East is rich in hydel power resource, Sindh in the South is rich in wind and coal resource, and Baluchistan in the West is rich in solar resource. Pakistan′s future energy must come from a balanced mix of all these sources, while it must gradually reduce its dependence on the imported oil. The power demand in the country will rise to over 110 GW by the year 2030, and Pakistan should gear up to face that. It is estimated that an average of over 12 GW of actually available wind power can be integrated into the national grid by 2030. Another 21 GW may be added through hydel resource, which will bring the total installed hydel power capacity to nearly 30 GW. The balance power demand will have to be met from solar and other resources. The current need is to carry out the detailed feasibility studies for harnessing solar power on larger scales, so that this resource may start making meaningful contributions during the next decade. A determined political will is the key to energy independence.

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